Structural Properties of Some Biomolecules In The GHz Region Using Dielectric Spectroscopy

Synopsis

Submitted to

SWAMI RAMANAND TEERTH MARATHWADA UNIVERSITY,
NANDED

By

Miss. Suad Abdullah Haidar Alwaleedy

Under the Supervision

of

DR. A.V. SARODE
(Assistant Professor)
School of Physical Sciences
Swami Ramanand Teerth Marathwada University, Nanded

Structural Properties of Some Biomolecules In The GHz Region Using Dielectric Spectroscopy

Introduction:

The proposed research work is aimed at the study of dielectric relaxation and thermo physical behavior of some biomolecules/biopolymers in the high frequency (Ghz) region through their molecular interaction with solvent environment. This proposed study may be useful for getting valuable information about structure and dynamics of biomolecules/biopolymers or biomaterials using different spectroscopic techniques [1-10]. Biomolecules play an important role in physical, chemical and biological processes and are very important class of organic compounds. Dielectric properties of biological macromolecules have been the subject of experimental and theoretical studies for quite longer time. These properties are greatly affected by the presence of water [1-8] and other solvents to an extent that this behavior could be used as a means of investigating the role of solvent in the various biomolecules/biopolymers. The characterization of the dielectric properties in terms of the state of hydration, concentration, frequency and temperature, might provide useful data from which the molecular processes underlying the macroscopic results could be analyzed [11].

Conformational transformations of biopolymers and biomolecules generally leads to substantial changes of the dielectric properties which reflect the accompanying

changes of overall structure. Properties of biomolecules changes with temperature, solute-solvent concentration and other parameters [12]. Some biomolecules and biopolymers containing oxygen atoms or –OH groups can enter into intra and/or intermolecular hydrogen bonding giving rise to several conformers in different solvents. The polar nature of biomolecules determines their behavior in aqueous solutions and allows studying their dynamics and structure using broadband dielectric spectroscopy [13]. Fundamental function of biomolecules is governed by a delicate balance of electric and electrodynamic forces within and among them . The electric nature of biomolecules can be described by their dielectric properties, which influence the distribution of electromagnetic fields and determine a behavior of biomolecules in electric field. Hence, dielectric and polarization properties of the biomolecules are essential for (i) fundamental understanding of biomolecular interactions and for (ii) understanding of external electric field interaction with biological matter at the nanoscale[14].The dielectric spectroscopy DS method occupies a special place among the numerous modern methods used for physical and chemical analysis of material, because it enables investigation of dielectric relaxation processes in an extremely wide range of characteristic times (10^{4}- 10^{-12}) s . Although the method does not possess the selectivity of nuclear magnetic resonance NMR or electron paramagnetic resonance ESR it offers important and sometimes unique information of the dynamic and structural properties of substances. DS is especially sensitive to interface polarization and intermolecular dipole-dipole interactions, and cooperative processes may be monitored. It provides a link between the properties of the individual constituents of a

complex material and the characterization of its bulk properties [15]. Despite several efforts devoted to the study of investigation of structural and dynamical properties of biomolecules and biopolymers over many years, there are still many interesting aspects of molecular interaction and spectroscopic behavior, which have not been understood thoroughly. Therefore, it is important to study the structural and dynamical behavior of such biomolecules in its pure liquid state or in different solvents by changing its environment (concentration, temperature etc,.).

Literature review:

There are several books and literature on biomolecules, biopolymer and spectroscopic techniques available to understand the molecular behavior for the said systems [12,16-18]. The interactions between the solvent and the various constituent groups of a protein, such as the amino acid side chains and the backbone peptide group, play a crucial role in the structure and function of proteins in aqueous solutions. Dielectric relaxation measurements on aqueous solutions of alanine and phenylalanine were carried out by chaudhari et al [19] using time domain reflectometry (TDR) at 25, 30, 35, and 40 _C in the frequency range from 10 MHz to 20 GHz. Dielectric spectroscopic study for water in amino acids solutions have been carried out by Evgeniya Levy et al [20]. The effect of microwave frequencies on the structural and dynamical properties of heterocyclic organic compound such as Indole in the surrounding of DMSO (Dimethyl sulphoxide) molecule has been studied over the temperature region 298.15 K to273.15 K using Time Domain Reflectometry (TDR) in

the frequency region of 10 MHz-50 GHz studied by Komal B. Kabara et al[21] .The dielectric increments for the first ten members of the homologous series of a,w-amino acids, to- gather with those for a number of rigid or “pseudo rigid” molecules, have been calculated from dielectric constants in aqueous solution. The results suggest that the flexible molecules exist in their most extended conformations and that solvent effects contribute significantly to the observed dielectric increments studied by J. T. Edward et.al [22]. The complex dielectric permittivity of eight different amino acids in water solutions was determined in the frequency range from 0.2 to 20 GHz at room temperature, trying to span the whole range of solubility in each case studied by In˜igo Rodrı´guez-Arteche.et.al[23]. the complex (electric) permittivity of aqueous solutions of dipolar solutes has been measured as a function of frequency between 1 MHz and 40 GHz studied by udo kaatze et al [24]. Molar dielectric increments at 25 ^{O}C for several aliphatic amino acids and betaines have been determined from the dielectric constants of their dilute aqueous solutions studied by J. Kirchnerova.rt.al.[25]

A standard Fro¨hlich-Kirkwood dipole moment fluctuation model has been used to calculate the static dielectric permittivity, for four different proteins, each of which was simulated under at least two different conditions of pH, temperature, solvation, or ligand binding studied by Jed W. PiteraJune.et.al.[26].Measurements of the complex permittivity of one, two and three molar e-aminocaproic acid solutions have been made in the frequency range 70 to 2000 Mc/s and at temperatures between 10 and 40°C studied by J. C. W. Shepherded .et.al.[27].

studied the dependence of amino-acid dielectric relaxation on solute-water interaction: molecular dynamics studied by Jiri Pr˚uˇsa.et.al.[28].Dielectric Spectroscopy of Biomolecules up to 110 GHz In the early days studied by Eva-Maria Laux .et.al[29]

The dielectric properties of the proteins insulin, chymotrypsinogen, salmine sulphate and bovine serum albumin, the peptides glycylglycine and diglycyl- glycine, and the amino acids glycine and glutamic acid, in the solid crystalline state have been studied, in most cases over both the frequency range 300 to 4 X 10^9 c./sec. and the temperature range – 100^0 to o^o c studied by S. T. BAYLEY .et.al[30].A simple inhomogeneous model of protein dielectric properties has been discussed by Xueyu Song et al. A protein in solution was modeled as a collection of polarizable dipoles in a cavity embedded inside a dielectric medium. The intrinsic polarizabilities of 20 amino acids weree assumed to be portable to all proteins in nature studied by Xueyu Song.et.al.[31]

Objective of research:

The main objective of the proposed research work is to carry out and study molecular interaction, structural and dynamical behavior of some biomolecules when environment of such a systems i.e. temperature, concentration, number of atoms, frequency and other parameters changes. The study of biomolecules may be carried out through dielectric properties such as dielectric constant ,static permittivity, relaxation time and the results may be corroborated with the thermodynamic parameters such as activation Entropy, Enthalpy and Free energy using time domain dielectric spectroscopy in the GHz region. The effect of molecular weight, temperature

and concentration on biomolecules will also be the thrust areas of this work while studying molecular behavior and physical properties using dielectric spectroscopic techniques.

Methodology :

Various techniques are available to study the molecular interaction, structural and dynamical behavior of biomolecules and biopolymers such as Fourier Transform Infra-Red (FTIR) [32-33], X-Ray[34-35],Nuclear Magnetic Resonance (NMR) [36] and Dielectric spectroscopy[9,37-41].

In the present work we will use some of these techniques to obtain information on the structural, dynamical and molecular interaction in biomolecules and biopolymers. Effect of concentration, frequency and temperature may also be included in the study.

Importance of study/ Society application:

➢ International status/ National Status:

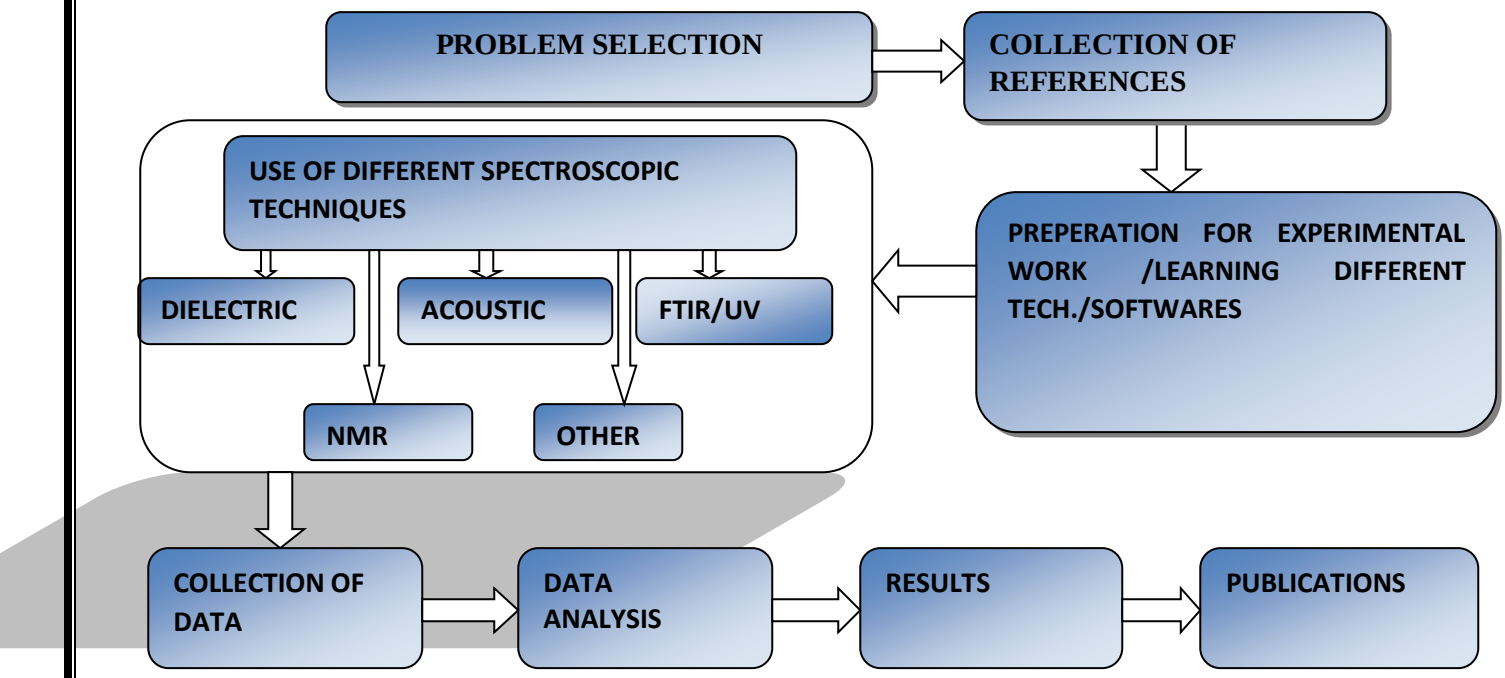
Biomolecules: biomolecules and biopolymers finds a variety of applications in every field. The applications of biomolecules are not only restricted to our life but it extends to other applications also. Recently, preparation of nanomaterial by the use of the special properties of biomolecules has gained more and more research interest. Preparation of nanomaterials with the use of biomolecules can often has some control on the morphology and size of the final products [42]. Biomolecules are also used for the development of biosensors and their applications [43]. Because of their applications in every field it is really important to study structural and

dynamical properties of biomolecules. Because of wide applications of biomolecules in nearly every field of science, engineering and technology, it is indeed important to look into molecular interaction, structural and dynamical properties of polymers using spectroscopic methods.

➢ ***Significance of the study*** :

The process of molecular biology generally display a high degree of specificity and efficiency unknown for simpler thermophysical and physico-chemica phenomena. These peculiar properties can be attributed to appropriately evolved control and regulation mechanisms in which certain biomoleculs and biopolymers play a vital role. Such macromolecular compounds usually have definite conformations which are of cruisial significance for their biological function therefore it will be of the greatest importance to elucidate the nature of pertinent structures and their functionl potentialities. Therefore, the study of biomolecules/bioplymers will be helpful in understanding the structural and dynamical behavior of molecules in different environment (i.e. temperature, concentration,etc.) using the dielectric parameters like dielectric permittivity, dielectic constant, relaxation time and thermodynamical parameters such as entropy of activation, enthalpy of activation, free energy and many other physical parameters.

Proposed work Plan/ Formulation and Structure of Study:



➢ Year-wise Plan of work and targets to be achieved

Year/months	Target to be achieved
1-6 months	collection of References
7-13 months	Learning Different techniques
14-20 months	Experimental Work
21-36 months	Analysis
37-48 months	Project completion Report, Publication, Communication etc.

References:

1. G. LoÈffler, H.Schreiber and O.Steinhauser J. Mol. Biol. (1997) 270, 520-534.
2. B. M. Fischer, H. Helm, and P.U. Jepsen ”Chemical recognition with broadband THz spectroscopy,” Proceedings of the IEEE, Special Issue on: T-ray Biosensing and Security, Invited 2-02-2005, to appear 2006.
3. S. Gorenflo, I. Hinkov, A. Lambrecht, B. Fischer, M. Hoffmann, H. Helm,P Uhd Jepsen ”Low-power terahertz time-domain spectroscopy with optimized electro-optical detection” TM-Technisches Messen 72 (7-8): 430-439, 2005.
4. B.M. Fischer, M. Hoffmann, H. Helm, G. Modjesch and P. Uhd Jepsen ”Chemical recognition in THz time-domain spectroscopy and imaging”,Semiconductor Science and Technology 20(7): 246-253 2004.
5. B. M. Fischer, M. Hoffmann, H. Helm, R. Wilk, F. Rutz, T. KleineOstmann, M. Koch M, P. Uhd Jepsen ”Terahertz time-domain spectroscopy and imaging of artificial RNA” Optics Express 13 (14): 5205-5215, 2005.
6. P. Uhd Jepsen and B.M. Fischer ”Dynamic range in terahertz time domain transmission and reflection spectroscopy” Optics Letters 30(1): 29-31, 2005.
7. M. Walther, B.M. Fischer, P. Uhd Jepsen ”Noncovalent intermolecular forces in polycrystalline and amorphous saccarides in the far-infrared” Chemical Physics 228 261-268, 2003
8. B M Fischer, M. Walther, and P. Uhd Jepsen ”Far-infrared vibrational modes of DNA components studied by terahertz time-domain spectroscopy” Phys. Med. Biol. 47(21):3807-3814, 2002
9. A.V. Sarode, R.N. Gacche and A.C. Kumbharkhane, RSC Advances
10. D. J. Bakewell, N. Vergara-Irigaray and D. Holmes, JSM Nanotechnology & Nanomedicine, 1(1), 1003, 2013.

11. Nadir A.G.Ahmed, Thesis, electric and magnetic properties of the enzyme lysozyme and other biomolecules.

12. M. Davies and G. Schwarz, Dielectric and Related Molecular Processes : Volume 1, RSC Publisher, (1972).

13. Rodríguez-Arteche, I., Cerveny, S., Alegría, Á., & Colmenero, J. (2012). Dielectric spectroscopy in the GHz region on fully hydrated zwitterionic amino acids. *Physical Chemistry Chemical Physics*, *14*(32), 11352-11362.

14. Havelka, D., Krivosudský, O., Průša, J., & Cifra, M. (2018). Rational design of sensor for broadband dielectric spectroscopy of biomolecules. *Sensors and Actuators B: Chemical*, *273*, 62-69.

15. Feldman, Y., Ermolina, I., & Hayashi, Y. (2003). Time domain dielectric spectroscopy study of biological systems. *IEEE transactions on dielectrics and electrical insulation*, *10*(5), 728-753.

16. M. Davies, Dielectric and Related Molecular Processes , publisher Chemical Society (Great Britain) –1972.

17. W.E. Vaughan,Digest of literature on dielectric, Vol. 37 (1975), publisher :National Academy of Sciences, Washington D.C.

18. Water and Biomolecules: Physical Chemistry of Life Phenomena, Edited by :Kunihiro Kuwajima, Yuji Goto, Fumio Hirata, Masahide Terazima, Mikio Kataoka,

19. H. C. Chaudhari,a Ajay Chaudharib* and S. C. Mehrotra, *Journal of the Chinese Chemical Society*, **2005**, *52*, 5-10

20. Levy, E., Cerveny, S., Ermolina, I., Puzenko, A., & Feldman, Y. (2014). Dielectric spectra broadening as a signature for dipole-matrix interaction. IV. Water in amino acids solutions. *The Journal of chemical physics*, *140*(13), 04B604_1.

21. Kabara, K. B., Wananje, K. H., Kumbharkhane, A. C., & Sarode, A. V. (2020). Dielectric behavior of indole in the GHz region using TDR. *Journal of Molecular Liquids*, *299*, 112137.

22. Edward, J. T., Farrell, P. G., & Job, J. L. (1974). Dielectric increments of amino acids. *Journal of the American Chemical Society*, *96*(3), 902-906.

23. Rodríguez-Arteche, I., Cerveny, S., Alegría, Á., & Colmenero, J. (2012). Dielectric spectroscopy in the GHz region on fully hydrated zwitterionic amino acids. *Physical Chemistry Chemical Physics*, *14*(32), 11352-11362.

24. Kaatze, U., Bieler, H., & Pottel, R. (1985). Dielectric spectroscopy on aqueous solutions of some zwitterionic amino acids. *Journal of molecular liquids*, *30*(2), 101-113.

25. Kirchnerova, J., Farrell, P. G., & Edward, J. T. (1976). Dielectric increments and the conformations of amino acids and betaines in water. *The Journal of Physical Chemistry*, *80*(18), 1974-1980.

26. Pitera, J. W., Falta, M., & van Gunsteren, W. F. (2001). Dielectric properties of proteins from simulation: the effects of solvent, ligands, pH, and temperature. *Biophysical journal*, *80*(6), 2546-2555.

27. Shepherd, J. C. W., & Grant, E. H. (1968). Dielectric properties of amino acid solutions I. Dielectric dispersion in aqueous ε-aminocaproic acid solutions. *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*, *307*(1490), 335-344.

28. Průša, J., & Cifra, M. (2020). Dependence of amino-acid dielectric relaxation on solute-water interaction: Molecular dynamics study. *Journal of Molecular Liquids*, *303*, 112613.

29. Laux, E. M., Ermilova, E., Pannwitz, D., Gibbons, J., Hölzel, R., & Bier, F. F. (2018). Dielectric spectroscopy of biomolecules up to 110 GHz. *Frequenz*, *72*(3-4), 135-140.

30. Bayley, S. T. (1951). The dielectric properties of various solid crystalline proteins, amino acids and peptides. *Transactions of the Faraday Society*, *47*, 509-517.

31. Song, X. (2002). An inhomogeneous model of protein dielectric properties: Intrinsic polarizabilities of amino acids. *The Journal of chemical physics*, *116*(21), 9359-9363.

32. T. Ding Far infrared spectroscopy of biomolecules: a THz-TDS, FTIR and computational study PhD Thesis, Aust Institute for Bioengineering & Nanotechnology, The University of Queensland. 2011.

33. M. Boese, K.Fahmy, Biomolecular interactions studied by FT-IR-ATR spectroscopy, spectroscopy of Biological Molecules, 1999, pp 41-42.

34. Subramaniyam S., Fisher H.F., Biopolymers,11,1305,1972.

35. Kubinek M.G., Wemmer D.E., Curr. Opin. Struct. Biol. 2,828,1992.

36. Minoru Fukuzaki, Toshihino Umehara, D. Kurita, et al. J. Physical Chemistry 96(25), 10087,1992.

37. A .V. Sarode, A.C. Kumbharkhane, Polymer International, 61(4),2012.

38. A .V. Sarode, A.C. Kumbharkhane, J. Molecular Liquids, 160(2),2011.

39. A .V. Sarode, A.C. Kumbharkhane, J. Molecular Liquids, 163,2011.

40. Feldman, Y. D., Zuev, Y. F., Polygalov, E. A., & Fedotov, V. D. (1992). Time domain dielectric spectroscopy. A new effective tool for physical chemistry investigation. *Colloid and Polymer Science*, *270*(8), 768-780.

41. Jones, S. B., Wraith, J. M., & Or, D. (2002). Time domain reflectometry measurement principles and applications. *Hydrological processes*, *16*(1), 141-153.

42. Zhuang Li and Tao Yang, 309-5, Published: August 1, 2011, biomedical engineering

43. Sandeep K. Sharma[a], Neeta Sehgal[b], Ashok Kumar, Current Applied PhysicsVolume 3, Issues 2–3, April 2003, Pages 307–316.

Signature

Research Scholar

Signature

Research Supervisor / Guide / Co-guide